SHORT COMMUNICATION

Preliminary survey of the setal and sensory structures on the pedipalps of camel spiders (Arachnida: Solifugae)

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Abstract. Solifuges, or camel spiders (order Solifugae), keep their pedipalps extended when moving through the environment, utilizing them much the way insects use their antennae. The male also uses his pedipalps during copulation, staying in contact with the female throughout the process. The pedipalps are covered with setae that are assumed to function as chemo-, mechano-, thermo-, hygro-, and olfactory receptors. We surveyed setal forms and other possible sensory structures on the pedipalps of solifuges to determine 1) if certain setae and structures are common to all families, 2) if some may be unique to certain families, and 3) the possible function of the various setae and other structures. We found that all families had bifurcated and tapered setae, and that all families had dorsal tarsal pores. Other setal forms were evident only in one or a few families. Three of the setal types had distal pores suggesting that they function as chemoreceptors. These data suggest that the pattern and types of setae on the pedipalps of solifuges may be phylogenetically informative and confirm that the pedipalps do function as sensory appendages.

Keywords: Chemoreceptor, mechanoreceptor, sensory receptor, Blumenthal organ, tarsal organ

Arachnologists have studied solifuges for decades, yet solifuge biology is still elusive (Punzo 1998). In particular, only a few studies have been carried out to elucidate the functional significance of morphological structures unique to these arachnids (Bertkau 1892; Roewer 1934; Junqua 1966; Brownell & Farley 1974; Haupt 1982; Bauchhenss 1983; Cushing et al. 2005; Klann et al. 2005, 2008; Klann & Alberti 2010).

The pedipalps, in particular, are in need of morphological study. Solifuges keep their pedipalps anteriorly extended when moving through the environment (Punzo 1998). They utilize them during hunting, as they have suctorial organs to help bring prey closer to their chelicerae (Cushing et al. 2005; Klann et al. 2008; Willemart et al. 2011). Males also use their pedipalps during mating, staying in contact with the females through the entire process, suggesting that there may be structures on the pedipalps functioning in intraspecific communication. Haupt (1982) looked at the morphology of chemotactile setae on the second and third legs of solifuges, and Bauchhenss (1983) examined the morphology and ultrastructure of sensilla ampullacea on the pedipalps. Beyond these studies and those on the suctorial organ (Cushing et al. 2005; Klann et al. 2008), little other work has been done on the sensory structures found on the appendages of solifuges. The objective of this study was to carry out a preliminary survey of the setae and other possible sensory structures found on the pedipalps of 12 species representing each of the 12 families in the order.

We used Scanning Electron Microscopy (SEM) to examine the setal morphology of the pedipalps of solifuges that represent the 12 families of the order (Table 1). We used a FEI Quanta 450 Field Emission Gun at the U.S. Geological Service (USGS) Denver Microbeam Laboratory. To prepare each specimen, we cut off the right pedipalp at the coxus, washed off any obvious dirt with absolute ethanol and sonicated the pedipalp in absolute ethanol for 30–45 seconds. We then allowed the pedipalp to air dry before examining it under the light microscope to make sure visible impurities were minimal. Depending on the size of the pedipalp, we either mounted the pedipalp on a 12.5 mm diameter aluminum stub or on a glass slide. The pedipalps were mounted with double-sided sticky carbon tape. We used the USGS Microbeam Lab protocol to gold sputter the stubs for 35–45 seconds and then placed them into the SEM for examination. We photographed an entire view of each segment of the pedipalp in order to pinpoint setae of interest (Fig. 1A). We then magnified and photographed individual setae (Fig. 1B). Next, we focused on the tip and the base of each unique seta (Figs. 1C, 1D).

Table 1.—Specimens used for SEM analysis. AMNH = American Museum of Natural History, CAS = California Academy of Sciences, DMNS = Denver Museum of Nature and Science, SMN = National Museum of Namibia.

Stub #	Specimen #	Family	Species
Am1	DMNS ZA.23498	Ammotrechidae	*Branchia angustus* Muma 1951
Ce1	SMN 13632	Ceromidae	*Ceroma inerme* Purcell 1899
Da1	SMN 13278	Daesiidae	*Biton browni* (Lawrence 1965)
Er1	DMNS ZA.22647	Eremobatidae	*Eremobates pallipes* (Say 1823)
Ga1	AMNH 4624	Galeodidae	*Galeodes olivieri* Simon 1879
Gy1	SMN 13632	Gylippidae	*Trichotoma michaelseni* (Kraepelin 1914)
He1	AMNH 5768	Hexisopodidae	*Chelypus barberi* Purcell 1902
Ka1	AMNH 10687	Karschiidae	*Karschia mastigofera* Birula 1890
Me1	AMNH 10737	Melanoblossidae	*Melanoblossia braunsi* Purcell 1903
Mu1	CAS 9033889	Mummuciidae	*Mummucia* sp.
Rh1	AMNH 2293	Rhagodidae	*Rhagodes melanus* (Olivier 1807)
So1	AMNH 7569	Solpugidae	*Zeria sericea* (Pocock 1897)

Figure 1.—Pedipalp segments and structures that were photographed. A) Tarsal segment of *Rhagodes melanus* (Rhagodidae), B) seta on femur of *Trichotoma michaelseni* (Gylippidae), C) base of seta on metatarsus of *Eremobates pallipes* (Eremobatidae), D) tip of seta on metatarsus of *Ceroma inerme* (Ceromidae). Scale line A = 3 mm, scale line B = 50 μm, scale lines C & D = 2 μm.

We found 13 distinguishable setal types, mostly defined by the shape of the shaft and tip (Figs. 2A–M, Table 2). All sensory setae emerged from morphologically similar sunken pits. Thus, we mostly show only the tips and parts of the shafts of the different setae in Fig. 2. Table 2 summarizes how common each type of seta is among the 12 families. The bifurcated seta (Fig. 2A) and tapered tip seta (Fig. 2K) are common to all families. Some families such as Ceromidae (*Ceroma inerme* Purcell 1899) and Daesiidae [*Biton browni*

[Lawrence 1965)] seem to have unique setae (Figs. 2F, H, I). The nozzle tip seta (Fig. 2F), one type of truncated tip seta (Fig. 2M), and the tapered tip seta (Fig. 2K) all have terminal pores; thus, we suspect these function as chemoreceptors. Arthropod chemoreceptors can generally be distinguished by an apical pore (Slifer 1970; Foelix 1970; Foelix & Chu-Wang 1972; Harris & Mill 1973; Zacharuk 1980; Barth 2001; Talarico et al. 2006). The other setal types lack pores and may function as mechanoreceptors or as other types of sensory receptors (e.g., hygroreceptors, thermoreceptors, proprioreceptors).

The other structures found on the surface of the pedipalps may have some phylogenetic importance. Hexisopodidae (*Chelypus barberi* Purcell 1902) was the only family with spines on the tarsus, although additional species from the various families must be examined. Dorsal tarsal pores were seen in all 12 species representing the 12 families (Figs. 3A–D). These structures have been previously described (Bertkau 1892; Bauchhenss 1983). They occur in fields, containing a few to dozens of pores within a field along the dorsal surface of the tarsi (Figs. 3A, C). The shape of these fields may be phylogenetically informative; e.g., in *Galeodes olivieri* (Galeodidae), the field of pores extends diagonally from the proximo-medial surface of the tarsus, across the dorsal surface, ending at the anterio-lateral surface of the segment (Bauchhenss 1983 and Fig. 3A), whereas in *C. barberi* the pores are in two parallel groups down the dorsal surface of the tarsus (Fig. 3C). There were fewer tarsal pores on the pedipalps of *Mummucia* sp. (Mummuciidae) and *Melanoblossia brannsi* Purcell 1903 (Melanoblossidae). Bauchhenss (1983) suggested that reduction in the number of pores may be an adaptation against water loss through evaporation, although this hypothesis will have to be tested. These pores are hypothesized to be homologous to Blumenthal's tarsal organs in Araneae, which are hypothesized to function as olfactory organs (Bauchhenss 1983; Foelix 2011). Metatarsal pits were very apparent on the pedipalps of *C. barberi* (Figs. 3E–F); however, further analysis is required to determine the possible function of these structures. The concave shapes of the pits are noticeable enough to suggest that they may be of sensory importance. The pits are distributed evenly around the surface of the metatarsus (Fig. 3E).

This preliminary study of the sensory setae and structures on the pedipalps of Solifugae has revealed structures common to all families

Table 2.—Distribution of setae among the twelve families.

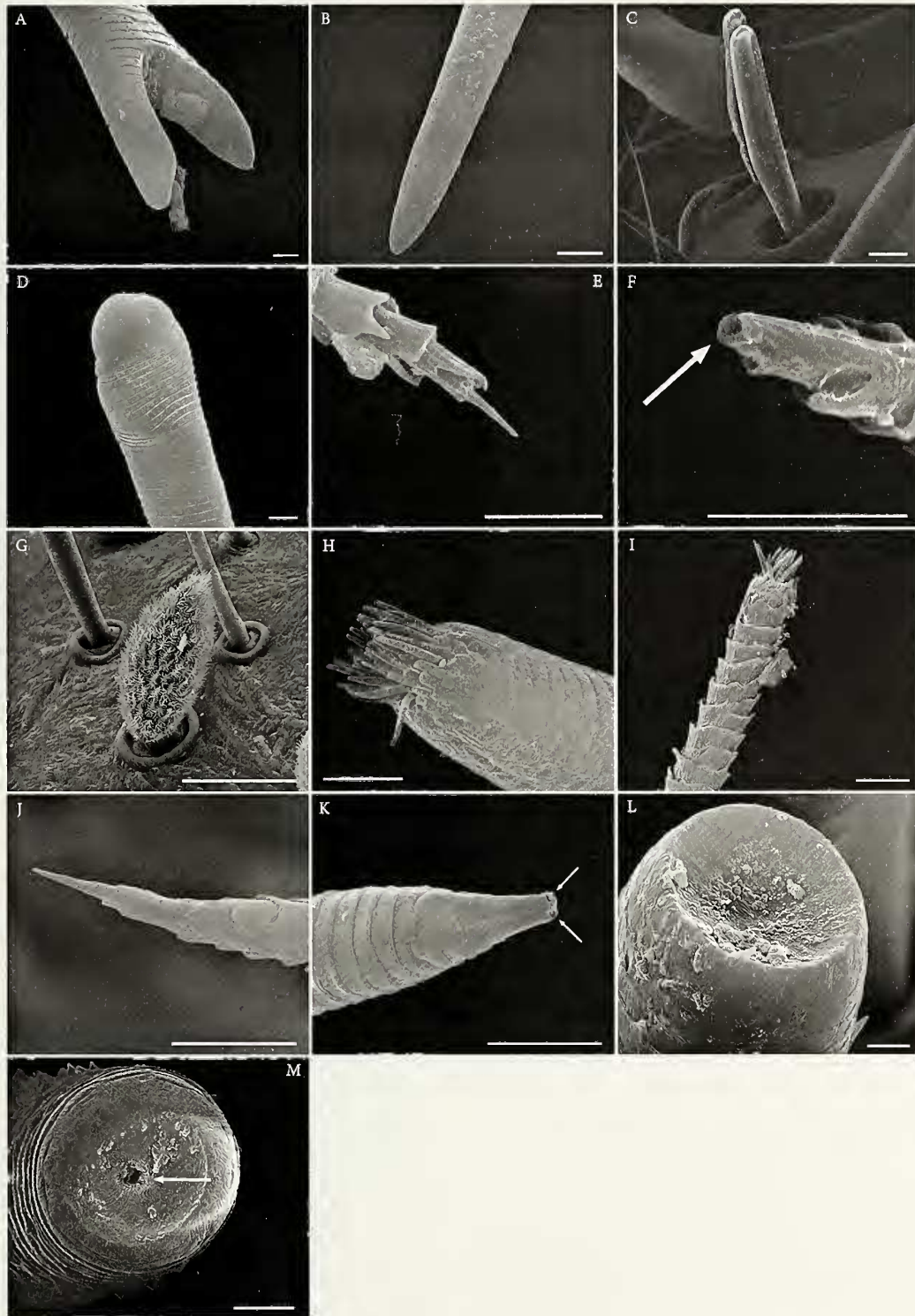| Setal types	Ammotrechidae	Ceromidae	Daesiidae	Eremobatidae	Galeodidae	Gylippidae	Hexisopodidae	Karschiidae	Melanoblossidae	Mummuciidae	Rhagodidae	Solpugidae
Bifurcated	X	X	X	X	X	X	X	X	X	X	X	X
Blunt		X		X	X	X	X	X	X	X	X	
Cavitate baton					X							
Clubbed				X					X	X		X
Imbricate		X	X	X	X	X	X		X	X		
Nozzle		X										
Papillae				X				X				X
Polymicrodigitus annulus			X									
Polymicrodigitus imbricate			X									
Simple		X	X									
Tapered	X	X	X	X	X	X	X	X	X	X	X	X
Truncated	X	X	X	X	X	X				X		X
Truncated with pore	X											
Metatarsal pits							X					
Tarsal pores	X	X	X	X	X	X	X	X	X	X	X	X

Figure 2.—Setal types found on the pedipalps of solifuges. A) Bifurcated seta tip on tarsus of *Ceroma inerme* (Ceromidae), B) blunt seta tip on the tibia of *Trichotoma michaelseni* (Gylippidae), C) cavitate baton seta on metatarsus on *Galeodes olivieri* (Galeodidae), D) clubbed seta tip on tarsus of *Eremobates pallipes* (Eremobatidae), E) imbricate seta tip on tibia of *C. inerme*, F) nozzle seta tip on femur of *C. inerme* (arrow points to pore), G) papilla on metatarsus of *E. pallipes*, H) polymicrodigitus (annulus) seta tip on femur of *Biton browni* (Daesiidae), I) polymicrodigitus (imbricate) seta tip on femur of *B. browni*, J) simple seta tip on femur of *E. pallipes*, K) tapered seta tip on tarsus of *B. browni*, L) truncated seta tip on tarsus of *T. michaelseni* with no pore evident, M) truncated seta tip on tarsus of *Brauchia angustus* (Ammotrechidae) (arrow points to pore). All scale lines = 2 μm except G = 50 μm.
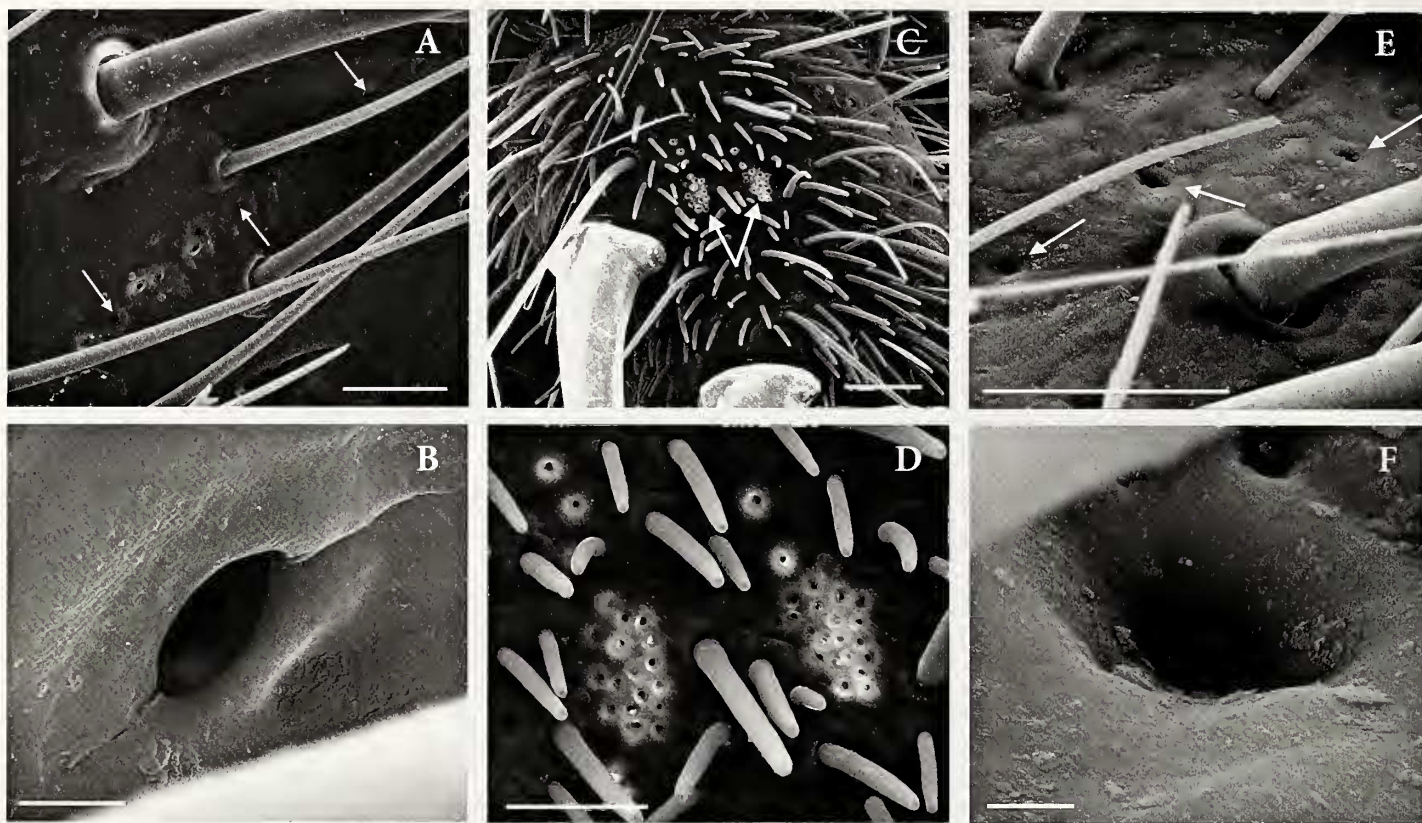
Figure 3.—Other structures found on the pedipalps of solifuges. A) Dorsal tarsal pore field of *Galeodes olivieri* (Galeodidae) (arrows point to pores), B) single dorsal tarsal pore of *G. olivieri*, C) tarsus with parallel dorsal tarsal pore fields of *Chelypus barberi* (Hexisopodidae) (arrows point to pore fields), D) dorsal tarsal pore field of *C. barberi*, E) distribution of metatarsal pits of *C. barberi* (arrows point to pits), F) metatarsal pit of *C. barberi*. Scale lines B & F = 2 µm; scale lines A, E, & D = 50 µm; scale line C = 100 µm.

such as the dorsal tarsal pores. We have also identified setae common to all families and setae that may be unique to individual families. Additional taxa within each of the 12 families must be examined in the future to verify the apparent phylogenetic usefulness of these sensory structures. In addition, in order to determine the function of the different types of setae, three experiments should be performed: 1) electrophysiology to detect mechano-, chemo-, hygro-, thermo-, and olfactory reception; 2) histological analysis to map out dendritic placement and help confirm function; and 3) behavioral studies to analyze setal function in their environment. Nevertheless, the present study verifies that the pedipalps of solifuges do play a major role in sensory perception.

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